ON THE RELATIONS OF THE GREAT MARLBOROUGH CONGLOMERATE TO THE UNDERLYING FORMATIONS IN THE MIDDLE CLARENCE VALLEY, NEW ZEALAND

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INTRODUCTION

McKay, in describing the geology of the Cape Campbell district in 1877, mentioned "conglomerates, composed in chief part of well-rounded bowlders, but having a large percentage of angular blocks of great size, so that on the surface they often present the appearance of old Morainic accumulations." His description continues as follows: "A great variety of rocks are represented in these conglomerates—old slates and sandstones, and even crystalline rocks from the inland ranges; volcanic rocks from the Amuri group; green sandstone from the Saurian beds; and great masses of Amuri limestone—as before mentioned large bowlders of conglomerate from the Awatere beds, as well as limestones, sandstones, and shell conglomerates belonging to the same."[1] In the section accompanying McKay's report[2] the deposit is represented as superficial, lying on the upturned edges of the "Saurian beds"

[1] A. McKay, *Geol. Surv. of N.Z., Rep. Geol. Expl. during 1874–76*, p. 190, 1877.

[2] *Op. cit.*, BB, opp. p. 188.

(Cretaceous), and its correlation is suggested with "the high-level shelly conglomerates at Amuri Bluff,"[1] which are probably Pleistocene.

Some years later the same geologist found deposits of similar type, which he regarded as parts of the same formation, at various places in Eastern Marlborough. The most conspicuous and characteristic of these are several outcrops in the neighborhood of Kekerangu,[2] that forming Deadman's Hill,[3] and a long strip in the Middle Clarence Valley.[4]

The beds exposed in Heaver's Creek, Kekerangu, are described by McKay in the following terms:

> They are rudely stratified, at places showing that the beds are standing nearly vertical; in the lower part are enormous blocks of Amuri limestone and masses of soft marly strata, which it seems impossible to convey any distance and deposit in the position in which they are found. Saurian concretions from the Amuri beds, and bowlders containing Awatere fossils, are also plentiful. . . . . It is impossible to give any description which will convey a correct idea of the pellmell manner in which the various materials of this conglomerate breccia are mixed together. Well-rounded sandstone conglomerates are confusedly mixed with angular blocks of all sizes up to 12 ft. or 15 ft. in diameter, divided into thick beds by thin beds of sandy and clay beds, which themselves are not evenly bedded, but twist and wind among the coarser materials as though the beds had been thrown into undulations prior to their being upheaved and subsequently brought into their present position by faulting."[5]

Hector[6] mentions, in the same section, the most finely laminated silts with fossil plants in the midst of the coarse conglomerate.

Both Hector[7] and McKay always regarded the conglomerate as unconformable to the beds on which it rests, and it is thus represented in all their sections illustrating structure in the Clarence Valley and also at Deadman's Hill.[8] In all these cases, it is repre-

[1] *Op. cit.*, p. 191.

[2] A. McKay, *Geol. Surv. of N.Z., Rep. Geol. Expl. during 1885*, pp. 114–16, 1886; *ibid.* (*1888–89*), pp. 169–71, 1890.

[3] *Op. cit.* (*1886*), pp. 116–17; *ibid.* (*1890*), pp. 171–72.

[4] *Ibid.* (*1886*), pp. 118–22; *ibid.* (*1890*), pp. 174–78.

[5] A. McKay, *op. cit.* (*1886*), p. 115.

[6] Sir James Hector, *Geol. Surv. of N.Z., Progr. Rep. for 1885*, p. xxxvi, 1886.

[7] *Ibid.*, p. xvi.

[8] See, for example, Hector, *op. cit.*, p. xxxv; McKay, *op. cit.* (*1886*), pp. 94, 95, 116.

sented as following the Grey Marl, a formation which, in the classification adopted by Hector's Survey, was classed as Cretaceo-Tertiary, i.e., older than Upper Eocene. Since the conglomerate contains bowlders of fossiliferous rock, which McKay regarded as derived from the Awatere beds (believed to be of Miocene age), the reason for regarding it as unconformable to the underlying series is apparent.

It was recognized that the accumulation of the conglomerate took place prior to the earth movements that gave rise to the Kaikoura and Seaward Kaikoura ranges,[1] but one of the lines of argument on which McKay relied to prove his contention was undoubtedly a mistaken one. He argued that, since no beds had been discovered in place in the neighborhood from which the fossiliferous Tertiary blocks in the conglomerate could have been derived, these bowlders had been transported across the site of the Kaikoura Ranges, before their uplift, from a known outcrop of similar rocks far to the southwest.[2]

Recently, however, Thomson[3] has discovered a bed of marine, fossiliferous, Tertiary sandstone, apparently interstratified between two coarse bands of the conglomerate forming Deadman's Hill, which is identical with the material of the blocks in the conglomerate in that locality formerly regarded as exotic. The large bowlders, moreover, in Deadman's Creek (or Shades Creek), the presence of which has been noted by various observers, come in reality from this outcrop of rock in place, and not, as has been supposed, from the conglomerate. The writer has also examined the locality in company with Dr. Thomson. The junction of the sandstone with the underlying band of conglomerate is not clear, and there is a bare possibility that the beds are separated by a fault (or thrust plane). If this is so, the sandstone may be the source of the fossiliferous bowlders in the underlying as well as in the overlying conglomerate beds. Whether this is the case or not, the discovery indicates the danger of assuming that any of the constituents

[1] Hector, *op. cit.*, p. xxxvi; McKay, *Geol. Surv. of N.Z., Rep. Geol. Expl. during 1890–91*, p. 95, 1892.

[2] A. McKay, *op. cit.* (*1892*), p. 4.

[3] J. Allan Thomson, *N.Z. Geol. Surv., 7th Ann. Rep.*, 1913, p. 123.

of the conglomerate are not of local origin because local outcrops of similar rock in place have not yet been found.

The same conglomerates have been described as glacial moraines by Park,[1] who assumes extensive glaciation in Eastern Marlborough in the Pleistocene period.

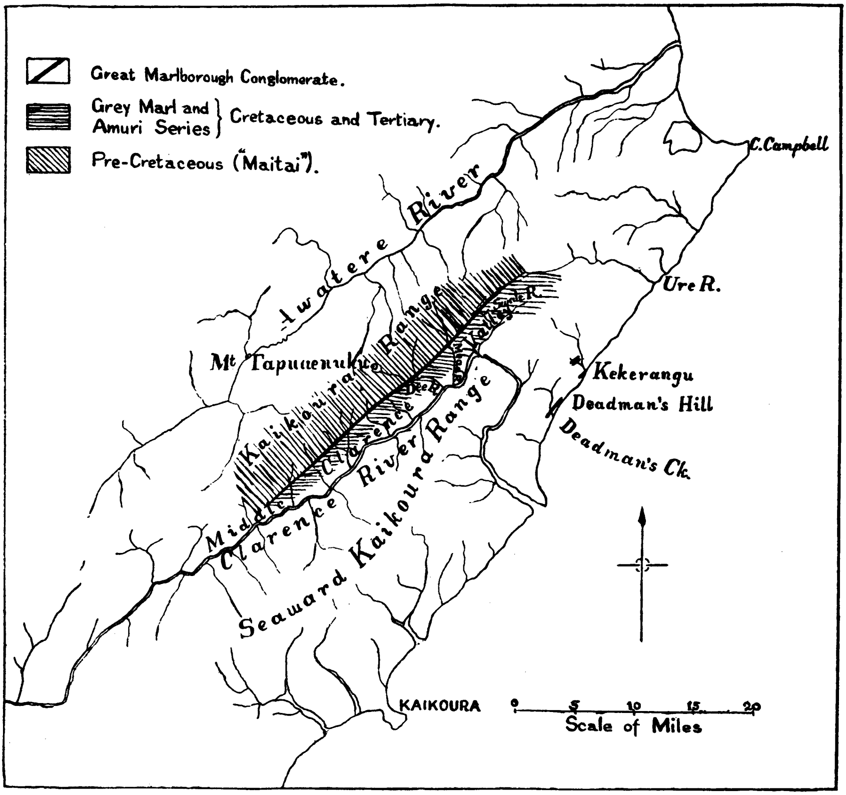

FIG. 1.—Locality map of Eastern Marlborough, New Zealand. Geology after McKay.

The writer has examined several outcrops in the neighborhood of Kekerangu, that forming Deadman's Hill, and also, at a number of points, the strip which follows the line of the Middle Clarence Valley. The outcrop near Cape Campbell was, however, in the limited time available, not found, although a great part of the

[1] J. Park, *Trans. N.Z. Inst.*, XLIII, 520–24, 1910; *Geology of New Zealand*, pp. 201–5, 1910.

area mapped by McKay[1] as conglomerate was traversed, and it therefore appears that the outcrop is much smaller than is indicated by McKay's map. The stratigraphy at Kekerangu and Deadman's Hill is much involved, and, if Dr. Thomson's discovery at Deadman's, already referred to, is excepted, the sections of the conglomerate there exposed throw little light on its stratigraphical relations.

The writer has, therefore, studied in greater detail the strip in the Middle Clarence Valley where, especially in the Dee and Mead gorges, the sections are clearer; and the results are presented in the following pages.

From what has been already said it is clear that our knowledge of the age of the beds is insufficient to warrant the use of the name "Great Post-Miocene Conglomerate" applied by McKay and the formation will therefore be referred to in this paper by the name "Great Marlborough Conglomerate" adopted by Thomson.[2]

CONCLUSIONS AS TO THE NATURE AND RELATIONS OF THE CONGLOMERATE

Briefly stated, the conclusions as to the nature and relations of the Great Marlborough Conglomerate reached by the writer are as follows:

1. It exhibits fairly regular stratification, always more or less parallel to that of the underlying series.

2. Its relation to the underlying series, wherever the junction has been examined, appears to be one of conformity.

3. It contains, in abundance, masses of rock derived from the underlying formations.

4. It is, in the main, a fluviatile deposit.

The second and third statements, which appear, at first sight, contradictory, may be otherwise stated thus: The conglomerate forms a "superposed series" with the beds on which it rests, but, with an adjoining area of the same beds, which has since been entirely removed by erosion, but which supplied much of the material of the conglomerate, it formed, when first laid down, an

[1] *Op. cit.* (*1877*), map, p. 188.

[2] J. Allan Thomson, *N.Z. Geol. Surv.*, *7th Ann. Rep.*, 1913, p. 123.

"apposed series."[1] The evidence in favor of these conclusions is set out in the following pages, and also a hypothesis to account for the peculiar features of the formation.

CONFORMABLE RELATION TO THE UNDERLYING BEDS

In the Middle Clarence Valley the conglomerate overlies the bluish-gray mudstone to which the name Grey Marl is generally applied, and this, in turn, conformably overlies the Amuri Limestone. Wherever examined the Amuri Limestone, Grey Marl,

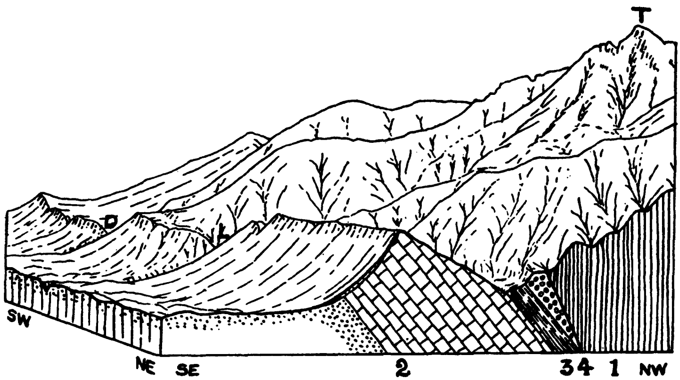

FIG. 2.—Diagram illustrating the occurrence of the Great Marlborough Conglomerate with the underlying Grey Marl and Amuri series in the Middle Clarence Valley, along the base of the Kaikoura Range.

The front of the diagram is a generalized section along the southwest side of the Mead River. (The dip of the fault plane in this section is hypothetical.)

D, Dee River; *L*, Limburne Stream; *T*, Mount Tapuaenuku

4, Great Marlborough Conglomerate

3, Grey Marl Series } Cretaceous and Tertiary
2, Amuri Series }

1, Pre-Cretaceous ("Maitai") Rocks. (Structure obscure)

and Great Marlborough Conglomerate have the same strike and dip, striking approximately northeast and dipping at high angles to the northwest, while the conglomerate is terminated upward by a reversed fault which runs for many miles, parallel to the strike of the above-mentioned beds, along the front of the Kaikoura Range, and brings the conglomerate against the old rocks of the range as indicated in Figs. 1 and 2.

In the gorge of the Mead River clear sections are exposed showing the relation of the conglomerate to the Grey Marl. The

[1] Cf. E. Suess, *The Face of the Earth*, I, 378–79 (Oxford, 1904).

junction plane, at the point examined, strikes N. 25° E., and dips at an angle of 47° to the west-northwest. The irregular bedding in the conglomerate is roughly parallel to the junction and apparently the junction is parallel to the bedding of the Gray Marl. In the latter, however, the only indication of stratification is given by discontinuous bands of concretions.

The upper layer of the Grey Marl is, lithologically, very similar to the Grey Marl as a whole except that it contains some broken shells and a few small pebbles or perhaps concretions of material similar to the Grey Marl but more indurated and containing shells in a bad state of preservation. These resemble larger masses, found close at hand, at a somewhat lower horizon, but still near the top of the Grey Marl series, which contain well-preserved fossils.[1] It is not quite clear whether they are derived bowlders or concretions. Thomson regards them as the former and considers that they indicate a certain amount of contemporaneous erosion.

Immediately overlying the upper layer of Grey Marl is a layer, 2 ins. in thickness, of conglomerate formed of various-sized rolled pebbles of graywacke (from the pre-Cretaceous formations). Next follows 2 ft. 6 ins. of bedded sandstone, covered by 1 ft. of mudstone, and that again is followed by many feet of fairly coarse conglomerate interbedded with sandstone and mudstone bands 1 ft. to 3 ft. in thickness, and with bands of very coarse conglomerate.

A distant view of the junction in the Mead gorge gives a false appearance of unconformity with discordance of dip, and led McKay to make the statement: "The overlying conglomerates are quite unconformable."[2]

This appearance of unconformity is due mainly to two causes:

1. Owing to the fact that the Grey Marl is a weak stratum, while both the underlying Amuri Limestone and the overlying conglomerate are very resistant, the valley of the Mead River is contracted into narrow, vertical-walled gorges where it crosses the conglomerate and limestone, but, between the two gorges, it opens out, with broadly flaring sides and a floor of considerable breadth, to form a nearly circular hollow on the outcrop of the

[1] J. Allan Thomson, *N.Z. Geol. Surv., 7th Ann. Rep.*, p. 123, 1913.

[2] A. McKay, *op. cit. (1886)*, p. 95 and section p. 94.

weaker rock. The junction between the Grey Marl and the conglomerate passes as a conspicuous line up the sides of this basin, and, since the face on which the section is exposed runs for some distance more nearly parallel to the strike than to the dip, the effect is to make the dip of the junction, when viewed from downstream, or from the center of the hollow, appear much more nearly horizontal than it really is. The apparent dip is, owing to the absence of a hard line of division between the Grey Marl and Amuri Limestone, compared by the eye with the true dip of the limestone outcropping in the monoclinal ridge (see Fig. 2), and there is thus produced the effect which was sketched by McKay as shown in Fig. 3.[1] Fig. 4, however, which is a photograph looking along the strike of the junction, shows that there is no appreciable discordance of dip.

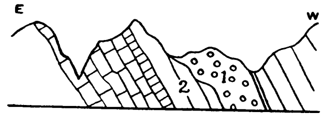

FIG. 3.—Part of McKay's section in the Mead River, showing the junction between the Grey Marl (2), and the Great Marlborough Conglomerate (1).

FIG. 4.—View of the junction between the Grey Marl and Great Marlborough Conglomerate, looking south-southwest across the Mead River.

2. Although the surface of junction between the Grey Marl and the conglomerate was originally plane, it is now broken by a number of small faults, each with a downthrow of only a few feet, which appear to be tension faults formed while the conglomerate and the underlying strata were in their original horizontal position. These, collectively, have let down, by trough-faulting, a wedge of conglomerate into the Grey Marl, giving the surface of junction a somewhat undulating form shown in Fig. 4, in which the faults can be seen.

[1] After McKay, *op. cit.* (*1886*), section p. 94; see also Hector, *op. cit.*, p. xxxvi.

A false appearance of bedding in the Grey Marl, nearly at right angles to the real stratification, is produced by the downward continuation of the faults, veins having been formed along the fault planes, which stand out a little from the bare, denuded surface of the weak marl.

In the Dee River (north branch) there is also a clear section showing the conformable relation between the Grey Marl and the conglomerate, in which the upper part of the Grey Marl is sandy, and contains near the top small pebbles of "Maitai" (pre-Cretaceous) graywacke, up to $\frac{1}{2}$ in. in diameter. Next follow lenticular masses of conglomerate composed of "Maitai" pebbles the largest of which are the size of a hen's egg, and from this there is a gradual passage to the typical conglomerate with sandstone bands.

COMPOSITION

The writer can confirm, in a general way, the descriptions of the conglomerate, at the various localities visited, as given by McKay, some of which were quoted on an earlier page.[1] McKay, however, in almost every description, reports the occurrence of coarse-grained igneous rocks resembling the intrusives of the Kaikoura Range, which have recently been described by Thomson.[2] These are referred to in the description of the Deadman's Hill conglomerate as follows: "Hornblendic and syenitic rocks brought from the central part of the Inland Kaikoura Range are very abundant."[3] In the Clarence Valley, on the watershed between the Ure and Swale, "abundance of crystalline dyke-rocks derived from the higher part of the Tapuaenuka Range" are reported in the conglomerate,[4] and McKay concluded that the abundant bowlders of igneous rock in the lower Ure River were derived from this source. The writer was unfortunately unable to examine the conglomerate closely at the source of the Ure, but a reconnaissance in the lower

[1] See also, for descriptions of the conglomerate at Deadman's Hill, McKay, *op. cit.* (*1886*), p. 116; (*1890*), p. 171; and for the Clarence Valley, McKay, *op. cit.* (*1886*), pp. 118–22; (*1890*), pp. 174–78.

[2] J. Allan Thomson, "On the Igneous Intrusions of Mt. Tapuaenuka," *Trans. N.Z. Inst.*, XLV, 308–15, 1913.

[3] McKay, *op. cit.* (*1886*), p. 116.

[4] *Ibid.* (*1886*), p. 119.

Ure valley showed that the great majority, at least, of the bowlders of igneous rock in the bed of that river were brought in by tributaries from the northeastern end of the Kaikoura Range where they are present in place. McKay states definitely that these rocks are present throughout a great part of the length of the outcrop in the Middle Clarence Valley[1] and notes their absence only at the southwest end of the strip.[2]

The writer, however, has been forced to conclude, from the results of his own examinations, in which Dr. J. A. Thomson kindly assisted, that igneous rocks of the Tapuaenuku type are absent from the conglomerate at all the points in the Clarence Valley at which it was examined. No such statement can, of course, be made with reference to the conglomerate at the source of the Ure.

The absence of these rocks from the conglomerate in the Dee gorge is especially significant since the intrusions are now exposed in the immediate vicinity and supply the bulk of the bowlders in the bed of the Dee.

The constituents of the conglomerate in the Dee and Mead gorges, as noted by the writer, are as follows:

In the gorge of the Dee.—Small well-rolled pebbles of pre-Cretaceous or "Maitai" rocks, both graywacke and jasperoid, are very abundant. Much rarer are lumps of Amuri Limestone of irregular, angular shape, up to the size of a man's head, and there are some pieces of flint, apparently derived from the flint beds which replace the basal part of the Amuri Limestone. Still more rare are lumps of very fossiliferous Tertiary sandstone, and of Cretaceous sandstone containing fragments of *Inoceramus;* these range up to 1 ft. in diameter. The largest blocks, generally several feet in diameter, are of crumbling, sandy marl or mudstone exactly agreeing, lithologically, with the upper beds of the Grey Marl present in place immediately below the conglomerate. All the larger blocks are arranged with their largest flat surfaces parallel to the stratification. There are present also some spherical concretions, 1 ft. to 2 ft. in diameter, resembling those in the Grey Marl. Igneous rocks are represented by bowlders of coarse-grained

[1] A. McKay, *op. cit.* (*1892*), p. 4.

[2] *Ibid.* (*1886*), p. 121.

basic, volcanic rock varying in size, the largest noted being 4 ft. in diameter, and by very rare, small pebbles of a fine-grained, porphyritic rock with small felspar phenocrysts.

Successive bands of conglomerate vary in coarseness, but there is no definite alternation or succession of coarser and finer strata. One conspicuously coarse band which occurs about 40 ft. from the base of the section in the main branch of the Dee is shown in Fig. 5. The large bowlders of which it is mainly composed are derived principally from the younger rocks, but large "Maitai" pebbles, up to 6 ins. in diameter, are present, and there are some rounded bowlders up to 6 ft. in diameter which may be either Cretaceous or pre-Cretaceous.

FIG. 5.—Coarse band in the Great Marlborough Conglomerate in the Dee gorge. View looking southwest.

In the gorge of the Mead.—In the Mead gorge the conglomerate is, on the whole, coarser than in the Dee, and here, more than anywhere else where it was examined by the writer, there is a mixture of fragments of all sizes. The very largest are rare, but blocks up to 2 ft. in diameter are common, and about one-third of the bulk is composed of bowlders over 6 ins. in diameter. All of them are water worn and most are fairly well rounded. Small pebbles are very abundant throughout, the majority of them being as small as or smaller than a hen's egg. They are fragments of the hardest of the pre-Cretaceous or "Maitai" rocks, smooth and well rounded, frequently almost spherical. There is in addition, both here and in the Dee, a large proportion of fine, sandy material filling the interstices, and the conglomerate is cemented into a very hard rock. The rocks represented are: large bowlders of the same coarse-grained, basic, volcanic rock that occurs in the Dee section; smaller and much rarer fragments of the fine-grained porphyritic rock also sparingly represented in the Dee; blocks of fine, Tertiary sandstone up to 2 ft. in diameter, crowded with shells and water worn (these

are the bowlders regarded by McKay as exotic, but Thomson[1] refers them to the same source as the possibly derived masses in the Grey Marl in this locality); Amuri Limestone, not very abundant, in blocks up to 6 ins. in diameter, but rarely larger; sandstone blocks of all sizes, some resembling the sandstones of the Cretaceous, others possibly pre-Cretaceous; pre-Cretaceous or "Maitai" pebbles, both graywacke and jasperoid, forming, as already mentioned, the bulk of the finer material. Fig. 6 is a photograph showing the general appearance of the conglomerate in the Mead section. In the Mead and Dee sections, as well as elsewhere, thin bands of sandstone occur throughout the conglomerate. They are referred to in the next paragraph.

FIG. 6.—The conglomerate in the gorge of the Mead. (The hammer handle is 10 inches long.)

FLUVIATILE ORIGIN

From the foregoing descriptions and from those quoted, as well as from the photographs of the conglomerate outcrops at Heaver's Creek, Kekerangu, and Kekerangu South Head published by Park,[2] it will be gathered that superficially the material resembles glacial morainic accumulations. Park[3] lays stress on the angular nature of some of the bowlders, but no polished or striated bowlders have as yet been described. "Large angular blocks" are certainly present, but it is also true that everywhere the bulk of the conglomerate consists of medium-sized to small pebbles of hard rocks, exceptionally well rounded. This fact was noted by McKay.[4] There is, moreover, almost everywhere a rough sorting into coarser

[1] J. Allan Thomson, *N.Z. Geol. Surv., 7th Ann. Rep.*, p. 123, 1913.

[2] J. Park, *Trans. N.Z. Inst.*, XLIII, Pls. 20, 22, 1910; *Geology of New Zealand*, Fig. 93, 1910.

[3] J. Park, "Marlborough Coastal Moraines," *Trans. N.Z. Inst.*, XLIII, 522, 1910.

[4] See, for example, *op. cit.* (*1886*), p. 115; *ibid.* (*1892*), p. 4.

and finer bands in the conglomerate itself, and fairly regular sandstone bands are universally present. These are clearly exposed in the gorge of the Dee, where the series is well stratified, with bands of coarse conglomerate and fine conglomerate, and thin bands of sandstone. In the Mead gorge a similar stratification is well marked, especially in the higher beds, and here the beds are seen to be lenticular, many of the sandstone beds especially thinning out to a feather edge.

In no case, on the other hand, has a distinct false bedding been noted, nor an arrangement of foreset beds that would indicate beach or delta conditions of subaqueous deposition. The beds were evidently laid down nearly horizontally and such deposition of coarse material appears to be impossible in standing water. It is practically certain, therefore, that the shallowing water of the Grey Marl sea was immediately filled when deposition of the conglomerate began, and that subsequently accumulation went on under subaerial conditions.

The character of the conglomerate supports the view that it accumulated under fluviatile conditions, and it presents many striking analogies with the terrestrial deposits in Owen's Valley, California, described by Trowbridge,[1] who has set out a list of criteria for the recognition of such deposits. Of these criteria the following, which appear to be the most valuable, are satisfied by the conglomerate:

1. In alluvial fans coarse material has a wide distribution as against confinement to a narrow zone near shore in standing-water deposits.

2. Textural range in single exposures is large in fan materials.

3. Fan materials are not in general so well sorted as deposits in standing water.

6. Fan material has a lens and pocket stratification, as against a sorting into more or less uniformly thick horizontal layers, as in lakes or seas.

7. Huge bowlders widely distributed vertically and horizontally in a deposit indicate that it was deposited by running water, and with a large proportion of fine material; that is, they indicate that the material is part of an alluvial fan deposit, except in cases where glaciers have affected it, or where standing waters could have received icebergs, or where basal conglomerates are formed near shore.

[1] A. C. Trowbridge, *Jour. Geol.*, XIX (1911), 706–47.

The continuity of the conglomerate in the Middle Clarence Valley throughout a line of outcrop thirty miles in length indicates that it was there deposited as a piedmont alluvial plain and not as isolated fans. A somewhat similar feature now in course of formation by several rivers, between the Seaward Kaikoura Mountains and the sea, in the vicinity of Kaikoura, constitutes the Kaikoura Plain.[1]

It may be noted that both Hector[2] and McKay[3] expressed their conviction that the conglomerate was of fluviatile origin, but both regarded it as the work of a single river system.

HYPOTHESIS TO ACCOUNT FOR THE PECULIAR FEATURES OF THE CONGLOMERATE

From the description in the preceding pages it is apparent that the Great Marlborough Conglomerate, in the Middle Clarence Valley, rests conformably on the Grey Marl, and yet is largely made up of material derived from that series and the beds conformably underlying it. Much of the material, moreover, agrees exactly in facies with the beds upon which it rests, and undoubtedly has been transported only a comparatively short distance.

In order to account for the supply of this material it is necessary to assume that a neighboring area was differentially elevated to the extent of perhaps as much as twelve thousand feet (the maximum thickness of the Amuri and Grey Marl series, as exposed in the neighboring Coverham section being estimated by McKay[4] at that amount), without seriously disturbing the horizontal attitude of that portion of the Amuri[5] and Grey Marl series, which, a little later, had the conglomerate deposited upon it, and which, as shown in Fig. 2, is, in part, still preserved.

Of the exact nature of this uplift no information is to be obtained, at least in the present state of our knowledge, from the pre-Cretaceous rocks in the vicinity, for their structure is obscure, nor

[1] See McKay, *op. cit.* (*1886*), p. 126.

[2] Sir James Hector, *op. cit.* (*1886*), p. xxxvi.

[3] A. McKay, *op. cit.* (*1892*), pp. 4–5.

[4] A. McKay, *op. cit.* (*1886*), p. 90.

[5] The Amuri Series as here understood includes the whole of the "Lower Greensand" and "Cretaceo-Tertiary" of Hector's Survey.

from the topography, for the main lines of the relief were determined by an orogenic uplift which took place after the deposition of the conglomerate.[1]

Of the three possible ways in which differential uplift might take place, namely, folding, warping, and block-faulting, the first two seem to be out of the question since the surface of the Grey Marl, in the area where it is preserved, was not appreciably tilted by the movement, and appears to have been neither elevated nor depressed to any extent by it. There remains the hypothesis of block-faulting with the restriction that the uplifted block alone moved.

Significance of faults in the conglomerate.—Movement of the nature of block-faulting, giving rise to mountains of the Basin Range type, usually takes place along normal faults,[2] and, for a long period after the main faulting, the formation of small normal faults continues, the younger faults so formed dislocating the fan deposits resulting from the erosion of the earlier fault scarp.[3] The occurrence of numerous small faults dislocating the Great Marlborough Conglomerate and the underlying series is, therefore, of some importance. In the Mead and Dee gorges, and in the gorge of the Limburne, a stream between the Mead and the Dee, the conglomerate, wherever examined, was found to be traversed by a number of faults with small throw. The fault planes are now in some cases nearly horizontal, and in others highly inclined, and the downthrow is fairly often found to be on the opposite side from the hade of the fault plane. If, however, the hade be measured from a normal to the plane of bedding, instead of from the vertical,

[1] C. A. Cotton, "Physiography of the Middle Clarence Valley," *Geographical Journal*, XLII (1913), 228.

[2] The advocates of lateral crustal extension and of some phase of crustal compression as the active agency in the formation of block mountains appear to agree that in most though not all cases the boundary faults hade toward the downthrow direction and that the planes of later movements on approximately the same lines are similarly normal fault planes.

[3] See G. K. Gilbert, *U.S. Geol. Surv., 2d Ann. Rep.*, p. 200, 1882; and *Monograph I*, pp. 340–57, 1890; I. C. Russell, *U.S. Geol. Surv., 4th Ann. Rep.*, pp. 451, 453, 1884; and *Monograph XI*, pp. 274–83, Pl. XXVIIIB, 1885; W. M. Davis, *Bull. Mus. Comp. Zoöl.*, XLII, 129–73, 1903; G. D. Louderback, *Bull. Geol. Soc. Am.*, XV, 322, 1904; A. C. Lawson, *Bull. Seismol. Soc. Am.*, II, 193–200, 1912.

the angle of hade is in no case great and the faults are all normal. There are, therefore, good grounds for the assumption that the faults were formed while the beds still lay in their original position.

One fault on the southwest side of the Dee gorge, which may be taken as an example, is illustrated in Fig. 7*a*. The line of fault, in the section exposed, slopes down to the east-southeast and makes an angle of 75° with the vertical, and a sandstone band in the conglomerate is displaced a distance of 4 ft. toward the east.

In the gorge of the Mead, as noted in an earlier paragraph, the faults are numerous, the fault planes striking about east and west. Fig. 7*b* is a sketch of one of them in the conglomerate gorge, which has a downthrow of 1 ft. 6 ins. to the south, and others are shown in Fig. 4. Very numerous faults can be seen in the Mead gorge passing down through the Grey Marl into the Amuri Limestone, but owing to the nature of these strata, the faults are less conspicuous in them than in the conglomerate.

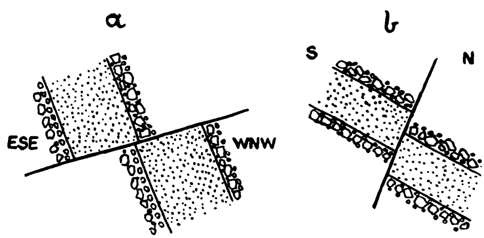

FIG. 7.—Faults in the Great Marlborough Conglomerate.

GEOLOGICAL HISTORY

During a long period extending from some time in the Cretaceous to well on in the Tertiary, deposition had been going on in the Middle Clarence Valley area under geosynclinal conditions, that is, upon a sea floor that sank gradually during the greater part of the period. Toward the end of the period of deposition of the Amuri Limestone subsidence ceased, and the character of the deposits became more and more argillaceous as the water shallowed. There is thus a gradual passage from the typical Amuri Limestone to the typical Grey Marl. The upper portion of the latter becomes somewhat sandy and contains layers of small pebbles from the old land. The presence of these does not necessarily imply uplift, but slight regional uplift, if it had occurred, would have sufficed to revive slightly the streams of the old land and so to increase

the supply of coarser waste. It is probable that the old land had previously been reduced to senile relief. Slight regional uplift would account for some contemporaneous erosion of the Grey Marl,[1] as it would bring the landward margin of the deposits into the zone of erosion, but it is possible that this is to be explained by slight differential uplift heralding the somewhat later uplift that supplied the material of the Great Marlborough Conglomerate. At this stage the maximum thickness of the accumulations in the geosyncline had reached about twelve thousand feet.[2]

According to the writer's hypothesis, a normal fault was next initiated approximately along or parallel to the line of the great reversed fault previously referred to (see Fig. 2), that was formed during a later period of folding, and now bounds the Clarence Valley on the northwest side, separating the conglomerate from the pre-Cretaceous rocks of the Kaikoura Range. The earlier normal fault, being a line of weakness, may have determined the position of the later reversed fault.

Uplift of the block northwest of the fault plane took place, initiating a period of active denudation along the fault scarp. Some portion of the old land appears to have participated in the uplift, and its revived streams no doubt kept up the supply of well-rolled "Maitai" pebbles which are common in the conglomerate. Some of these, however, may be a rewash of the basal conglomerate of the Amuri Series.[3] The streams from the old land, in their lower courses, crossed the uplifted younger rocks, and, as they emerged from young gorges in the fault scarp, built

[1] Thomson, *op. cit.* [2] McKay, *op. cit.*

[3] Since the above was written the writer has had an opportunity of reading a paper by A. C. Lawson entitled "The Petrographic Designation of Alluvial Fan Formations" (*Bull. Dep. Geol., Univ. Cal.*, VII, No. 15, 1913), in which the name *fanglomerate* is proposed for the class of deposit to which the Great Marlborough Conglomerate belongs. Lawson regards all rounded pebbles in fanglomerate as derived from older conglomerates, and, if it were possible in this case to regard them all as a rewash, both the amount of uplift and the area of the uplifted block that it is necessary to assume would be considerably less than on the hypothesis that they are derived from pre-Cretaceous rocks in place. The writer is not, however, prepared to admit that *all* the small well-rounded material is so derived, although a possible source of supply is the Cretaceous conglomerate (McKay, *op. cit.* [*1886*], p. 90), which locally, at

fans, the material of which was a mixture of angular blocks from near at hand and well-rolled pebbles brought from a distance. The presence of blocks with the facies of the underlying series is thus explained. The bowlders of volcanic rock, while they have not their equivalent in the immediately underlying series, are of the same type as the known volcanics of the Amuri Series which occur a few miles to the northwest in the Awatere Valley,[1] and it is quite possible that they were present in that portion of the Amuri Series that has been denuded off the site of the Kaikoura Range. The absence of the coarse-grained intrusive rocks of the Kaikoura Range, even if these should prove to be absent everywhere from the conglomerate, is not remarkable, and does not necessarily indicate that the date of their intrusion was later than that of the accumulation of the conglomerate. It indicates rather that the rocks of the present Kaikoura Range, which, it must be remembered, owes its present elevation to later folding, had not then suffered the enormous denudation which has exposed the intrusions. It is possible that the bowlders of volcanic rock in the conglomerate represent the more superficial equivalents of the deep-seated intrusions now exposed in the range.

The foregoing hypothetical explanation refers only to the strip of Great Marlborough Conglomerate following the line of the Middle Clarence Valley. The writer believes that the outcrops near the coast may be similarly explained, but further study of them is required, and an extension of the hypothesis to cover all occurrences of the conglomerate is beyond the scope of this paper.

several places in the northeast end of the Middle Clarence Valley, attains a considerable thickness, but is thin as a rule. The pebbles in the fanglomerate, on the other hand, seem to be uniformly abundant, indicating a uniform source of supply. The necessity arises also of accounting for the presence of the rounded pebbles in the transition beds from the Grey Marl to the fanglomerate, the deposition of which must have been contemporaneous with the beginning of movement on the fault plane, that is to say, must have preceded the exposure in the fault scarp of the deeply buried Cretaceous conglomerate. These pebbles at least must have come from the old land.

[1] McKay, *op. cit.* (*1890*), pp. 184–85.